

Bagaswoto *et al.*, 2016

Coronary Circulation and Hemodynamics

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Introduction

Coronary circulation is the circulation of blood in the blood vessels of the heart muscle (myocardium). The vessels that deliver oxygen-rich blood to the myocardium are known as coronary arteries. The vessels that remove the deoxygenated blood from the heart muscle are known as cardiac veins.

As the left and right coronary arteries run on the surface of the heart, they can be called epicardial coronary arteries. These arteries, when healthy, are capable of autoregulation to maintain coronary blood flow at levels appropriate to the needs of the heart muscle. These relatively narrow vessels are commonly affected by atherosclerosis and can become blocked, causing angina or a heart attack. The coronary arteries that run deep within the myocardium are referred to as subendocardial.

The coronary arteries are classified as “end circulation”, since they represent the only source of blood supply to the myocardium; there is very little redundant blood supply, which is why blockage of these vessels can be so critical.

Anatomy of Coronary Blood Flow

Oxygen and nutrients needs of the heart muscles come from the right and left coronary

arteries, which both came from the aorta artery.¹ Left main coronary artery (LM) branched into the left anterior descending (LAD) artery, which will run in interventricular groove on the surface of the anterior wall of the heart and left circumflexa (LCx) artery, which will run in the posterior along the groove located between the left atrium and ventricle. While the main right coronary artery (RCA), runs between the right atrium and ventricle toward the posterior part of the heart (Figure 1).² In most people, the two branches of the Cx and RCA contribute to provide blood flow to the left ventricle posterior part, which is referred to as a balanced circulation. While 10% of the normal heart, RCA its small size, and the posterior descending artery (PDA) are derived from LCx and provide a single blood supply to the posterior part of the left ventricle (left dominant circulation). There is also a less common right dominant circulation when LCx is small and left ventricular posterior part is supplied mainly by the left ventricular branch of RCA.³ Most of the coronary venous blood flow originating from the left ventricle muscle will return to the right atrium through the coronary sinus (covering 75% of the total coronary blood flow). Meanwhile, most of the coronary venous blood flow from the right ventricle muscle will return to the right atrium through the anterior cardiac vein, not through the coronary sinus.⁴

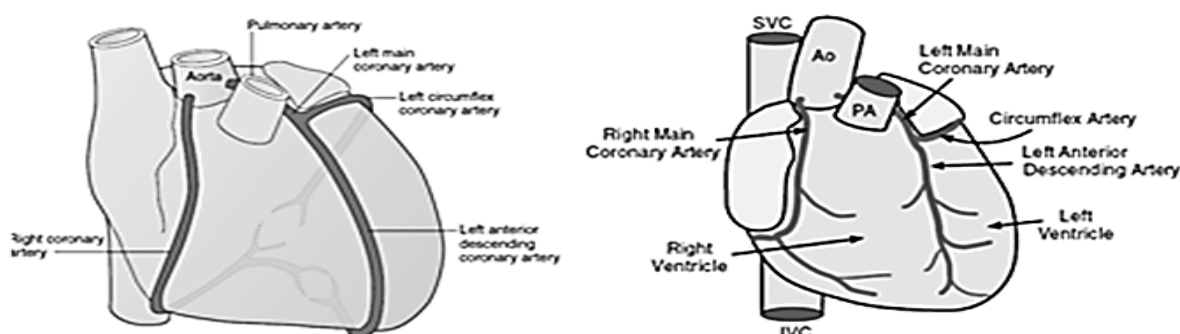


Figure 1. Right and left coronary arteries exiting from aorta, right above the aorta valve. Behind the pulmonary artery trunk, LM will branched out to be LAD and LCx and will carry blood for the left ventricle. Meanwhile, RCA will carry blood for the right atrium and ventricle, and inferoposterior part of the left ventricle (Source: Klabunde, 2012).

Physiology of Coronary Blood Flow

During the systolic phase, blood flow will be reduced, especially coronary blood flow in the innermost parts of the ventricular walls (i.e., sub endocardium) because this region has the highest compression capability. This is why the sub endocardium area is more susceptible to the incidence of ischemic injury when accompanied by coronary artery disease or occurs drop in aortic pressure.² Blood flow in the left coronary artery was almost absent during systolic phase, whereas 85% (60-80%) flow occurs when the diastolic (Figure 2).^{5,6}

When the ventricles begin to undergo the relaxation of early diastolic time, compression capability will disappear and coronary blood flow will increase. Coronary blood flow will reach its peak during the early diastolic and decreases passively in line with normal aortic pressure drop during the diastolic phase. Therefore, the magnitude of the aortic pressure during the diastolic phase is a condition that is crucial to the process of coronary artery perfusion. This explains why the increase in heart rate may decrease coronary perfusion. On a fast heart rate, duration of diastolic phase will be shortened, which will reduce the time for coronary perfusion. This will not be a problem with normal coronary arteries condition, as the coronary artery will dilate in line with the rise in heart rate and cardiac metabolism.

On the contrary, in case of a disease or disorder in coronary arteries that causes arterial vasodilation ability becomes limited, the increase in heart rate will restrict blood flow to the coronary and cause myocardial ischemia and angina pain.^{2,6} There is a difference between coronary blood flow

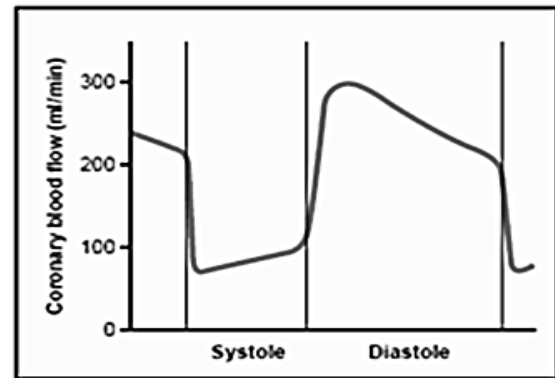


Figure 2. Phasic changes of the coronary blood flow during systolic and diastolic phase – an effect of heart muscle compression (Source : Klabunde, 2012)

that occurs between the left and right coronary arteries. As described above, in coronary blood flow through the coronary artery during systolic left will decrease, whereas the rate of blood flow in the right coronary artery was found highest for systolic. This matter occurs because aortic pressure affecting the flow is increased during the systolic (from 80 to 120 mmHg) compared to an increase in right ventricular pressure that impede the flow (from 0 to 25 mmHg) as shown in Figure 3.⁵ In addition, the wall stress in the right ventricle lower than the left ventricle, resulting in a higher blood flow in the right coronary artery during systolic than diastolic. In condition that increase wall stress in the right ventricle, such as pulmonary stenosis or pulmonary hypertension, there will be phasic changes in the right coronary artery flow, wherein coronary blood flow becomes lower during the systolic or even retrograde, resembling the flow in the coronary arteries that supply left ventricle.⁶

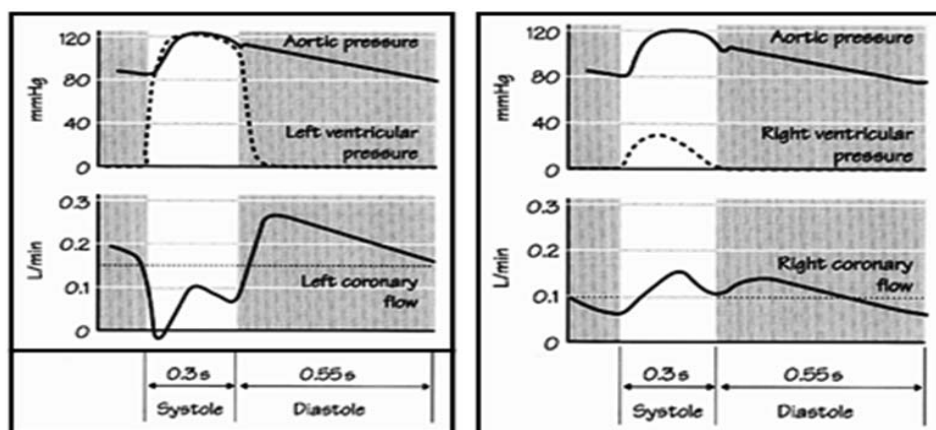


Figure 3. Blood flow in left and right coronary arteries during heart cycles, at a resting raate (70 times/ minutes) (Source : Wiener et al., 1999).

Table 1. Regulation mechanism of the coronary blood flow

<i>Mechanism</i>	<i>Definition</i>	<i>Target coronary vessel</i>
Endothelial	Vasoactivity of nitric oxide, endothelin, prostaglandins	Arteries; arterioles 80–150 μm
Metabolic	Vasoactivity of metabolites such as adenosine	Arterioles 25–100 μm
Myogenic	Vascular smooth muscle contraction and relaxation in response to rises and falls in intraluminal pressure	Arterioles 50–100 μm
Neurohumoral	Vasoactivity of neurotransmitters released from autonomic nerves, receptors, or circulating in the blood	Arterioles 140–300 μm arteries

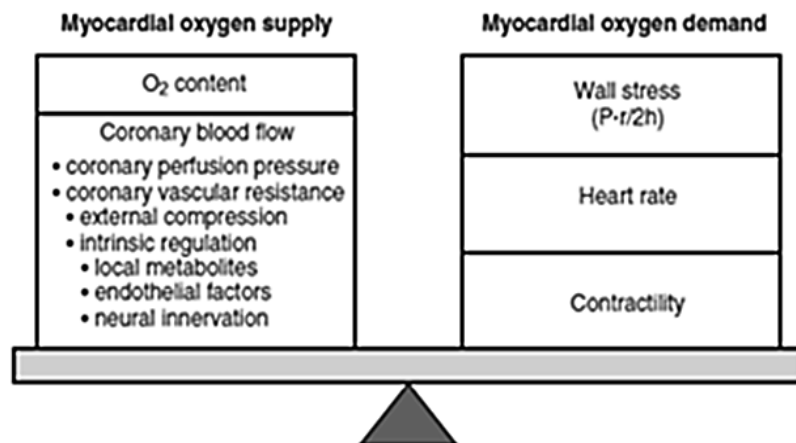


Figure 4. Factors that affect myocard/s oxygen supply and demand
(Source : Rhee *et al.*, 2011)

Coronary Blood Flow Settings

Coronary blood flow average varies between 80 mL / min per 100 grams of tissue when the heart breaks to more than 400 mL / min per 100 grams during activity. Therefore, normal coronary arteries have major vasodilation ability.²

Unlike most tissues, the heart cannot increase the extraction of oxygen as needed because even at the basal condition, the heart will take as much oxygen as possible from coronary blood flow. As a result, when the heart needs extra oxygen, it will be fulfilled by an increase in blood flow coroner and theauto regulation of the coronary vascular resistance holds a very important role in this process.⁷

Coronary blood flow is regulated by myogenic vascular tone and endogenous vasoactive compounds as shown in Table 1.⁶

Supply and Oxygen Demand of the Heart

In a normal heart, oxygen needed by the myocardium continuously be aligned with supply from the coronary arteries. Several factors will

affect the supply and myocardial oxygen demand as shown in Figure 4.⁷

Oxygen supply to the myocardium depends on the oxygen content in the blood and the rate of coronary blood flow. The oxygen content is determined by the concentration of hemoglobin and the level of systemic oxygenation. Meanwhile, coronary blood flow is more dynamic, and the mechanism is responsible to regulates coronary blood flow for adjusting the oxygen supply to the metabolic needs.⁶

There are three things that affect myocardial oxygen demand, namely (1) ventricular wall stress, (2) heart rate, and (3) contractility. An increase in myocardial tension, contractility, or the heart rate will cause an increase oxygen demand to be followed by an increase in blood flow in the coronary arteries and increase oxygen delivery.⁶ In normal conditions, coronary blood flow in the sub-endocardia area is 10- 30% higher than the blood flow in sub epicardium, because sub endocardiawall stress is higher so it uses more oxygen than sub epicardium. As a result, the sub endocardia area is more vulnerable to ischemia

when there is an obstruction in the coronary arteries.⁶

In the situation where there is coronary artery disease, the narrowing process that runs a chronic or impaired blood vessel function will cause a decrease in coronary blood flow (due to decreased vasodilation capability). When this occurs, the coronary blood flow cannot be adequately increased in line with increased myocardial oxygen demand. This situation leads to hypoxia in heart and will interfere with the function of cardiac contractility.²

Changes in Coronary Blood Flow in Coronary Artery Disease

Atherosclerosis process will lead to reduced diameter of the lumen of the artery, which eventually came to pass stenosis. This process usually occurs in the great epicardial arteries, although it can also happen to small blood vessels.²

Significant hemodynamic changes of the narrowing process of the coronary arteries depends on the degree of stenosis of coronary artery, epicardial vasodilation and compensatory ability of the distal coronary vessels that can be achieved (Figure 5).⁷

The final results of the myocardium condition due to ischemia depends on the severity and duration of an imbalance between supply and oxygen demand of the heart. Cardiac ischemia can cause irreversible myocardial necrosis (myocardial infarction) or a rapid and complete

recovery of function of myocytes (after a brief episode of angina). Ischemia sometimes can also cause its happening in sfungsi contractility prolonged without any myocyte necrosis and then followed with a perfect recovery. For example is stunned myocardium, referring to the network, after experiencing an acute episode of severe ischemia moment (but not necrosis), showed a systolic dysfunction despite prolonged myocardial blood flow has returned to normal. In this case, abnormality functional, biokemikal, and ultrastructural due to ischemia is irreversible and functions contractility improved gradually. Instead, hibernating myocardium refers to the network of dysfunctional contractility ventricular chronic running due to a decrease in blood flow that is persistent, usually due to coronary artery disease that *multivessel*. In this situation, irreversible myocardial damage has not occurred, and ventricular function can be immediately improved if the blood flow returns to normal (misal with coronary angioplasty or *bypass surgery*). Both of the above are very important later on in the day-to-day clinical application in determining when we still need to do mechanical reperfusion or not.⁷

When oxygen delivery is tampered by the presence of coronary disease, collateral vessels holds and important additional role to provide oxygen for the heart. The conditions of chronic stress (for example, chronic hypoxia or exercise) can cause the formation of new blood vessels through the process of angiogenesis. The presence of collateral blood vessels may increase myocardial oxygen supply by increasing the number of adjacent blood vessels, thus reducing vascular resistance in the myocardium. This helps supply blood flow to the ischemic area caused by the process of stenosis or thrombosis.² Several studies have shown a protective role of collateral in patients with coronary artery disease, which is shown in the form of infarcted area smaller⁸, the formation of left ventricular aneurysm rarer⁹, left ventricular function better and survival are better than patients who have coronary artery disease but without collateral.¹⁰

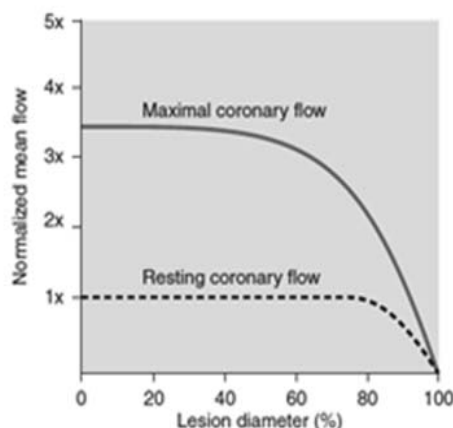


Figure 5. Resting and maximal coronary blood flow affected by degrees of stenosis that occurred at the proximal coronary arteries (Source : Rhee et al., 2011).

Conclusion

Coronary circulation plays an important role in meeting the nutritional needs of the heart. Under normal circumstances, the coronary circulations are responsible for maintaining the balance

between supply and oxygen demand of the heart. To fulfill that, the existence of a regulatory mechanism governing the coronary blood flow is required. If there is an imbalance between the heart's oxygen supply and demand, it would lead to a condition known as ischemia. One of the most frequent causes of this imbalance is the presence of coronary artery disease. The results of the final conditions of the myocardium due to ischemia depends on the severity and duration of an imbalance between oxygen supply and demand of the heart. Finally, on a patient with arterial coronary disease, the presence of collateral circulation participate have an important role in determining the severity of damage to the heart muscle due to a coronary artery occlusion.

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